Nuclear Power

Nuclear power is projected to represent a growing share of the developing world's electricity consumption from 1999 through 2020. New plant construction and license extensions for existing plants are expected to produce a net increase in world nuclear capacity.

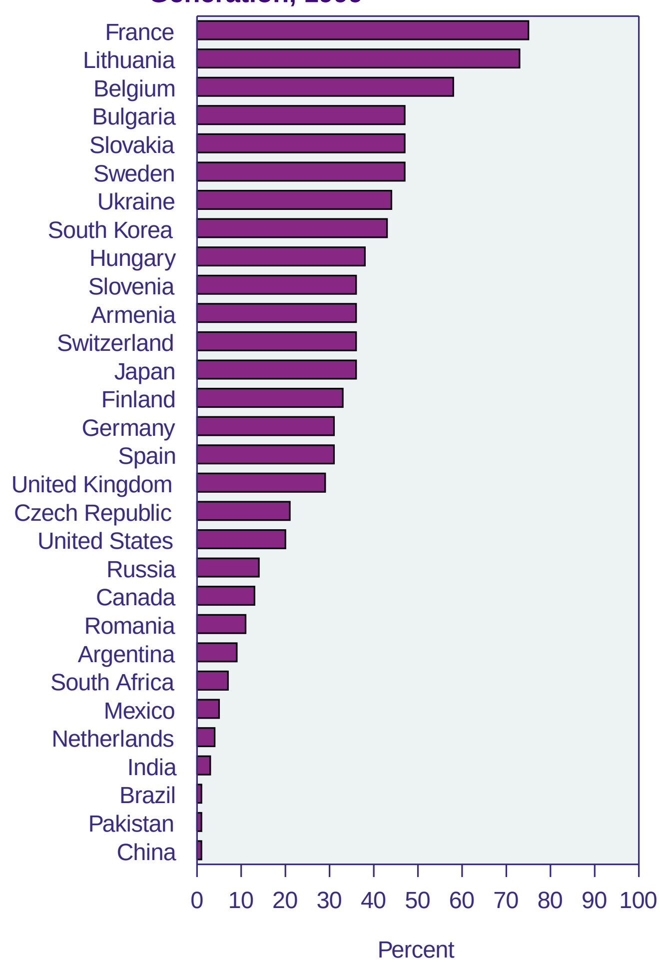
Nuclear power plants generated electricity in 29 countries in 1999. A total of 433 nuclear power reactors were in operation (Figure 61), including 104 in the United States, 59 in France, and 53 in Japan. The largest national share of electricity from nuclear power was in France, at 75 percent (Figure 62). Belgium, Bulgaria, France, Lithuania, Slovenia, Slovakia, Sweden, Ukraine, and South Korea depended on nuclear power for at least 40 percent of their electricity generation.

Energy from nuclear power first started to become a major source of electricity in the early 1970s, and from 1970 to 1980 world consumption of energy from nuclear power grew by about 700 percent (Figure 63). In 1979, however, the nuclear power plant accident at Three Mile Island did much to discourage further development of nuclear power in the United States. Similarly, the meltdown of the Soviet Union's Chernobyl plant in 1986 encouraged anti-nuclear public sentiment, particularly in Western Europe. Cost overruns for nuclear power plant construction projects in a number of countries also began to erode the confidence of investors. The growth in nuclear energy use worldwide slowed to about 200 percent in the 1980s, and in the 1990s it fell to roughly 20 percent.

Figure 61. Operating Nuclear Power Plants Worldwide, 1999

Source: International Atomic Energy Agency, *Nuclear Power Reactors in the World 1999* (Vienna, Austria, April 2000).

Figure 62. Nuclear Shares of National Electricity Generation, 1999



Source: Energy Information Administration, *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, January 2001).

In the *International Energy Outlook 2001* (*IEO2001*) reference case, nuclear energy use is projected to continue a modest increase through 2010, followed by a leveling off through the remainder of the forecast to 2020. The total increase in nuclear energy consumption from 1999 to 2020 is projected to be 8 percent.

Concerns over nuclear plant safety are among the factors that have slowed the growth in world nuclear power use. In addition to the Three Mile Island and Chernobyl incidents, more recent nuclear power accidents—such as the accidental criticality event at a nuclear fuel facility in Tokaimura, Japan, in 1999—have further reduced public enthusiasm for nuclear power. Proliferation of nuclear weapons is also of concern, in that several nations have developed nuclear weapons programs as offshoots of their civilian nuclear research programs since the 1960s. Recent explosions of nuclear devices in India and Pakistan have heightened those concerns. Cost is another factor that has worked against nuclear power in some countries, particularly during years of relatively low fossil fuel prices. The high capital costs of nuclear power plant construction can discourage investment in new capacity, particularly when interest rates are high.

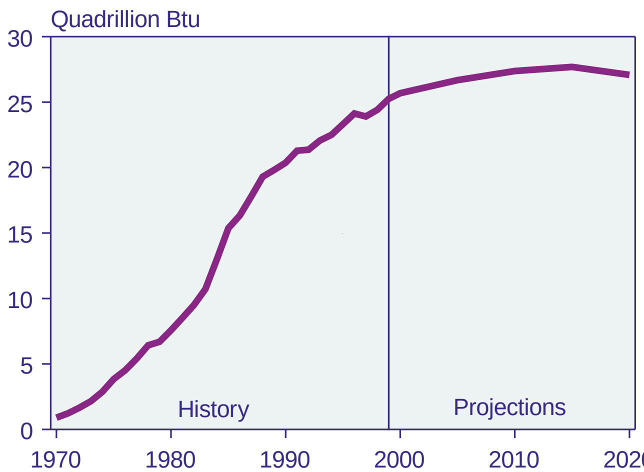
The industrialized nations accounted for about 80 percent of the world's total nuclear power capacity in 1999 (Table 18); however, the *IEO2001* reference case estimates that nuclear capacity in the industrialized nations will be 12 percent lower in 2020 than in 1999. In Western Europe, where nuclear power plants provided 35 percent of the energy used for electricity generation in 1999, a significant reduction in the nuclear share of electricity supply is expected by 2020. Finland and France in Western Europe, Japan in Asia, and Canada and Mexico in North Amercia are the only industrialized countries expected to maintain or expand their current levels of nuclear generation capacity.

Reduced reliance on nuclear energy is also expected in Eastern Europe and the former Soviet Union (the EE/FSU region), which accounted for 13 percent of the world's nuclear power generation capacity in 1999 but is projected to account for 11 percent in 2020. Many of the nuclear plants currently in operation or under construction in the EE/FSU region have been criticized as inherently unsafe according to Western operational safety practices. Several are currently slated for early retirement, and some of those currently under construction may never become operational.

In contrast to the industrialized world, the developing world is expected to more than double its nuclear generation capacity by 2020. In 1999 the developing world accounted for 8 percent of the world's nuclear electricity generation, but by 2020 it is projected to account for about 19 percent. The greatest expansion of nuclear generation capacity is expected in China, followed by South Korea and India. In 1999, 38 reactors were under construction in 14 developing countries (Figure 64), including 7 in China, 4 in South Korea, and 3 in India.

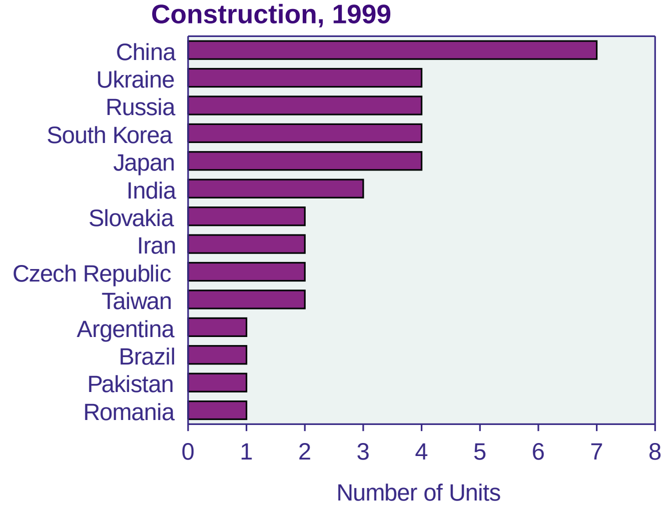
Recent events suggest that phaseouts of nuclear power could accelerate in some nations over the coming years. Belgium, Germany, the Netherlands, Sweden, and Switzerland are now officially committed to gradually shutting down their nuclear power industries [***1***]. Turkey, which until recently was expected to pursue nuclear power development, announced in 2000 that it

Figure 63. World Nuclear Energy Consumption, 1970-2020



Sources: **History:** International Atomic Energy Agency, *Nuclear Power Reactors in the World 1999* (Vienna, Austria, April 2000). **Projections:** Based on detailed assessments of country-specific nuclear power programs.

Figure 64. Nuclear Power Reactors Under Construction, 1999



Source: International Atomic Energy Agency, *Nuclear Power Reactors in the World 1999* (Vienna, Austria, April 2000).

Table 18. Historical and Projected Operable Nuclear Capacities by Region, 1999-2020
(Net Gigawatts)

Region	1999[a]	2005	2010	2015	2020
Reference Case					
Industrialized	**278.1**	**280.1**	**276.5**	**265.0**	**246.0**
United States	97.2	97.5	93.7	79.5	71.6
Other North America	11.3	14.1	14.9	14.9	14.9
Japan	43.7	44.5	47.6	56.6	56.6
France	63.1	64.3	64.3	64.3	63.1
United Kingdom	13.0	11.4	9.8	8.1	5.3
Other Western Europe	49.9	48.3	46.1	42.8	35.7
EE/FSU	**45.3**	**46.1**	**43.6**	**42.3**	**37.8**
Eastern Europe	10.6	11.6	10.0	10.6	10.6
Russia	19.8	21.7	21.3	17.6	13.1
Ukraine	12.1	11.2	12.1	13.1	13.1
Other FSU	2.7	1.6	0.0	1.0	1.0
Developing	**25.5**	**35.3**	**44.7**	**53.7**	**65.8**
China	2.2	5.9	9.6	11.6	18.7
South Korea	13.0	15.9	16.3	19.4	22.1
Other	10.3	13.5	18.8	22.7	25.0
Total World	**348.9**	**361.5**	**364.6**	**362.3**	**350.9**
Low Growth Case					
Industrialized	**278.1**	**272.3**	**254.4**	**207.1**	**180.8**
United States	97.2	96.8	89.9	65.6	55.3
Other North America	11.3	11.3	11.3	10.0	10.0
Japan	43.7	43.6	43.1	33.7	40.3
France	63.1	64.3	63.4	59.0	51.7
United Kingdom	13.0	11.0	8.1	4.2	1.8
Other Western Europe	49.9	45.3	38.6	34.7	21.8
EE/FSU	**45.3**	**42.2**	**36.7**	**27.9**	**14.0**
Eastern Europe	10.6	10.4	10.0	10.0	6.4
Russia	19.8	19.5	15.5	11.2	6.7
Ukraine	12.1	11.2	11.2	6.7	1.0
Other FSU	2.8	1.2	0.0	0.0	0.0
Developing	**25.5**	**31.7**	**39.4**	**44.1**	**46.0**
China	2.2	5.3	8.6	9.6	10.6
South Korea	13.0	14.9	16.2	18.5	20.2
Other	10.3	11.6	14.5	16.0	15.3
Total World	**348.9**	**346.3**	**330.5**	**279.0**	**240.9**
High Growth Case					
Industrialized	**278.1**	**284.6**	**295.1**	**301.6**	**301.7**
United States	97.2	97.5	96.9	94.3	88.5
Other North America	11.3	14.9	14.9	14.9	14.9
Japan	43.7	45.6	58.7	68.8	74.4
France	63.1	64.6	64.3	65.8	67.2
United Kingdom	13.0	12.3	11.0	10.6	11.4
Other Western Europe	49.9	49.9	49.3	47.3	45.3
EE/FSU	**45.3**	**49.2**	**49.7**	**49.1**	**55.0**
Eastern Europe	10.6	11.6	11.9	12.0	13.6
Russia	19.8	22.7	23.4	22.1	22.2
Ukraine	12.1	12.1	13.1	13.1	15.0
Other FSU	2.8	2.7	1.4	2.0	4.2
Developing	**25.5**	**38.3**	**56.1**	**73.7**	**88.7**
China	2.2	6.6	11.6	18.7	20.7
South Korea	13.0	16.8	19.7	21.4	26.2
Other	10.3	14.9	24.8	33.7	41.9
Total World	**348.9**	**372.1**	**400.9**	**424.5**	**445.3**

[a]Status as of December 31, 1999. Data are preliminary and may not match other EIA sources.

Notes: EE/FSU = Eastern Europe/Former Soviet Union. Totals may not equal sum of components due to independent rounding.

Sources: **United States:** Energy Information Administration, *Annual Energy Outlook 2001*, DOE/EIA-0383(2001) (Washington, DC, December 2000). **Foreign:** Based on detailed assessments of country-specific nuclear power programs.

has now put off doing so. In July 2000 Turkey's Prime Minister, Bulent Ecevit, announced the suspension of efforts to construct the nation's first nuclear power plant, the Akkuyu Bay project [***2***]. Turkey will instead rely on increased natural gas imports.

Thus far, only Sweden and Germany have committed to the early retirement of nuclear power plants. All other nations seeking to reduce their reliance on nuclear power intend to do so through attrition and by not building any new nuclear power plants. However, many nations may find that viable alternatives to nuclear power are more difficult to develop than anticipated. Sweden, for instance, after committing to closure of its two Barsebäck nuclear power units by 2001, put off the closure of Barsebäck 2 in 2000.

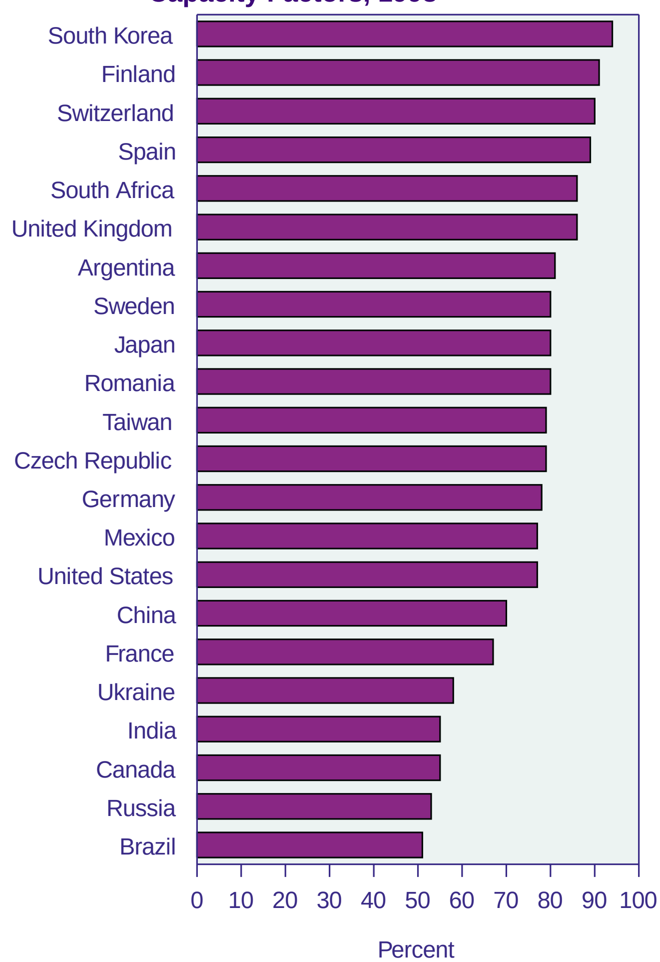
Not all recent nuclear power developments suggest a more rapidly contracting industry. In contrast to Europe, nuclear power's future in the United States may have improved slightly over the past year or two. In 2000, the industry regulator, the U.S. Nuclear Regulatory Commission (NRC), granted its first extensions to permit a company to operate two nuclear reactors 20 years beyond their initial 40-year operating licenses. Other U.S. companies have also petitioned the NRC for nuclear plant life extensions. In addition, a recent spate of mergers and acquisitions among U.S. nuclear power producing companies may improve the industry's financial health. Acquiring companies involved in recent U.S. nuclear merger and acquisition activities have often cited the prospects for future efficiency gains as a motivating factor for the industry's recent consolidation.

The late 1990s also saw the first instance of a foreign company purchasing a U.S. nuclear power unit. In December 1999, British Energy, through its AmerGen joint venture with PECO Energy of the United States, purchased the Clinton power station in Illinois [***3***]. One week after the Clinton acquisition, AmerGen announced that it intended to purchase Three Mile Island unit 1. British Energy currently owns 8 nuclear plants in the United Kingdom and has stated its intention to eventually acquire 20 nuclear power plants [***4***]. Subsequent to its joint venture with PECO, British Energy has also reached an agreement to lease and operate two of Canada's largest nuclear power plants [***5***]. Another UK company, British Nuclear Fuels Corporation, has joined with PECO Energy in a commitment to invest in South Africa's Pebble Bed Modular Reactor (PBMR) technology, which its promoters hope will do much to improve the prospects for nuclear power both in South Africa and globally (see box on page 88).

Recent improvements in operating performance may also have improved nuclear power's global prospects. The average availability factor for the world's nuclear power plants has improved from 72 percent in 1990 to 79 percent in 1998 [***6***], and the average for U.S. nuclear plants has risen from 62.2 percent in 1989 to 85.5 percent in 1999 [***7***]. Improved capacity utilization allowed the U.S. nuclear power industry to increase its net generation by 38 percent between 1989 and 1999[15] with only a 2-percent increase in U.S. nuclear capacity [***8***].

Measures of nuclear power plant efficiency in different countries vary considerably. For example, the average capacity factor for a given country's nuclear plants can vary over time as a result of scheduled maintenance outages. For 1998, national average capacity factors ranged from a high of 94 percent for South Korea to a low of 51 percent for Brazil (Figure 65).

Figure 65. National Average Nuclear Power Plant Capacity Factors, 1998



Source: Energy Information Administration, *Annual Energy Review 1999*, DOE/EIA-0384(99) (Washington, DC, July 2000), pp. 301 and 303.

[15] Measured as the net summer capability of operating units.

Regional Developments

Western Europe

Currently, among European countries, only France and Finland have shown any intent to expand their nuclear power industries. In May 2000, the Finnish Minister of Trade and Industry, Sinikka Mönkäre announced that she would back a new nuclear unit [***9***], noting that an increased role for nuclear power would be the only way for Finland to meet its Kyoto Protocol carbon reduction goals. Most of the other nations of Western Europe have decided either to curtail further development of nuclear power or to abandon it entirely. Belgium, Germany, the Netherlands, Spain, Sweden, and Switzerland have recently committed to gradual phaseouts of their nuclear power programs [***10***].

The move away from nuclear power in Europe is now several decades old. Italy discontinued its nuclear energy program in 1987 after a national referendum supported the shutdown of three operating power plants and a halt to construction on a fourth. Italy's parliament had voted against expanding the country's nuclear utility industry just after the 1986 Chernobyl accident. In 1990, Italy began to dismantle its four nuclear reactors.

In a referendum held in 1978, Austria voted to ban nuclear energy entirely. In 1999, the Austrian parliament added a clause into the nation's constitution declaring Austria to be a non-nuclear country, banning the building of nuclear power plants and storage facilities. As a result of the 1978 referendum, Austria had decided not to start the operation of its one nuclear power plant. Among Western European nations, Austria is the closest to Ukraine and was most affected by the Chernobyl disaster. Austria has since opposed the further development of nuclear power in neighboring Slovakia and the Czech Republic. Czech efforts to bring its Temelin plant into commercial operation in 2001 have met with Austrian attempts to defer the Czech Republic's entry into the European Union [***11***].

In 1984, Spain's then Socialist government imposed a moratorium on the construction of new nuclear power plants [***12***]. Spain's Socialist and Communist parties have called for a shutdown of the nation's nuclear power industry. The country intends to start shutting down its nine nuclear power plants in roughly 10 years.

Sweden and Germany have also adopted aggressive plans to end their nuclear power programs. In 1980 Sweden committed to a scheduled 40-year phaseout of nuclear power, and in November 1997 the Swedish parliament approved a plan to shut down two of the nation's twelve nuclear reactors, Barsebäck 1 and Barsebäck 2, which accounted for 12 percent of Sweden's nuclear generation capacity. Barsebäck 1, a 615-megawatt reactor that began commercial operation in 1975 [***13***], was shut down in November 1999, more than a year after the scheduled closing date of July 1998. Barsebäck 2, completed in 1977, was initially supposed to be closed in July 2001 [***14***], but in August 2000 the Swedish government announced that the Barsebäck 2 closure would also be delayed. After closing Barsebäck 1, Sweden replaced the lost electricity generation with imported power from coal-fired plant in Denmark, causing an increase in Western Europe's total carbon dioxide emissions.

In June 2000, Germany committed to ending its reliance on nuclear power. The plan calls for the shutdown of all Germany's reactors after they operated for 32 years. Accordingly, the final plant closure would occur in the mid-2020s. Germany's ruling government minority coalition partner, the environmentalist Green party, had favored a 10-year phase out. The Social Democratic German Chancellor, Gerhard Schroeder, initially favored a 20-year phase out but reached a compromise with the electric utility industry [***15***]. The German government also decided to eventually stop the foreign reprocessing of its spent nuclear fuels [***16***], but that decision was rescinded in early 2001, ending a 3-year moratorium on spent fuel shipments to foreign reprocessing plants [***17***].

In 1999, Belgium's coalition government adopted a program calling for the gradual closing of the country's nuclear power plants after 40 years of operational service [***18***]. Belgium's seven nuclear reactors accounted for 60 percent of the country's net electricity generation in 1997 [***19***]. Three reactors are scheduled to be decommissioned in 2015 and the remaining four in 2025 [***20***]. The Netherlands shut down one of its two reactors in 1997, and the other is slated to be shut down in 2004.

In 1990, 4 years after the Chernobyl accident, Swiss voters elected to impose a 10-year moratorium on nuclear power plant construction. In October 2000, the Swiss government decided to extend the moratorium to 2010 but did not place time limits on the lives of currently operating units, in light of the difficulties foreseen by Swiss policymakers in finding replacement power while meeting the need to reduce carbon dioxide emissions [***21***].

In general, Western Europe's heavy reliance on nuclear power to meet its electricity needs will make it difficult for many national governments to both phase out nuclear programs and meet their commitments to reduce greenhouse gas emissions under the terms of the Kyoto Protocol. For example, 47 percent of Sweden's electricity generation capacity in 1999 and 31 percent of Germany's was nuclear [***22***].

Pebble Bed Modular Reactors: A New Lease on Life for Nuclear Power?

In 1999, pressurized water reactors (PWRs) provided roughly half of the world's total nuclear electricity generation. Other reactor types in service around the world include boiling water reactors (BWRs), and pressurized heavy water reactors (PHWRs), among others. Since 1993, South Africa's state-owned utility, Eskom, has been working to develop a new commercial nuclear power technology, the pebble bed modular reactor (PBMR). Construction of the first PBMR is expected to begin in 2003, and it is scheduled to be operational in 2005.[a] If Eskom's estimates prove to be correct, the PBMR technology could be both safer and more economical than the nuclear power plants now in operation.

The fuel in PBMRs consists of billiard-ball-sized spheres of graphite "pebbles" containing ceramic-coated uranium dioxide particles. About 400,000 pebbles are spread about the graphite-lined reactor vessel to provide the critical mass needed for a sustained nuclear reaction. Helium at a temperature of 500°C is introduced at the top of the reactor.[b] The gas then circulates over the hot fuel pebbles, which increase its temperature to 900°C. The heated gas then flows into a gas turbine, which in turn drives a generator to produce electricity. The gas exits the turbines at 600°C and then flows into a recuperator, where the gas temperature is lowered to about 140°C. The gas temperature is reduced to about 30°C by a water-cooled precooler, then repressurized and passed back through the recuperator and sent back into the reactor. The process of using high-temperature gas as the working fluid to convert heat to mechanical energy (the turbine's rotational energy) is known as a direct Brayton cycle and, characteristically, has high thermal efficiency.

Eskom has high expectations for the new technology, estimating that it will be roughly equivalent in cost to South Africa's relatively inexpensive mine-sited coal-fired plants[c] and more economical than PWR technology. Other potential advantages being promoted by Eskom include design features that could reduce concerns about plant siting, operational safety, refueling outages, nuclear waste disposal, and nuclear arms proliferation.

The PBMR modular design is expected to improve the economics of the plant over conventional nuclear plants. Each unit, about the size of a single-family dwelling, would be factory-constructed, and the total construction time from the start of on-site construction to power generation is expected to be just 24 months when the technology is in full production.[d] The first unit is expected to have a capacity of 110 megawatts, about 10 percent of the generation capacity of a conventional PWR. The plant's relatively small size means that it would not necessarily have to be used for baseload capacity. As demand increased, modules could be added incrementally, and the units could be linked in clusters.

The PBMR technology could also overcome some of the siting problems associated with conventional nuclear plants. Because they do not use water as a coolant, PBMRs would not have to be sited near a body of water, and the passive safety features, in theory, would allow them to be located close to end users. South Africa intends to build PBMRs on the nation's eastern coast, where coal resources are not available, probably at Koeberg, where its one currently operating nuclear power plant is located.

Eskom expects the PBMR technology, employing passive safety features, to be safer than conventional nuclear reactor technologies. The helium coolant, although more expensive than water, would reduce the risk of a nuclear accident and could be used at very high temperatures without causing corrosion.[e] The graphite moderator would allow for much higher operating temperatures—750°C versus 350°C for a conventional PWR—which would eliminate the possibility of a core meltdown. If the PBMR system failed, it would simply shut down.

Another expected advantage is that, in theory, a PBMR could be refueled continuously while in operation, reducing the need for refueling outages. Fresh fuel pebbles could be added to the top of the PBMR fuel bed and old pellets removed from the bottom while the reactor remained in operation. Eskom estimates that its initial PBMR plant will approach an availability rate of 90 percent[f] (as compared with the 1999 U.S. average

(continued on page 89)

[a]"PECO Invests in Eskom's Project," *Africa News Service* (August 30, 2000), p. 1.

[b]Technology Services International, web site www.pbmr.co.za / Pebble_bed_new / preface_content.htm.

[c]"Eskom's Pebble Bed Reactor Presented to Government," *Nuclear News* (May 2000), p. 39.

[d]Technology Services International, web site www.pbmr.co.za / Pebble_bed_new / preface_content.htm.

[e]S. Thomas, "Arguments on the Construction of PBMR Reactors in South Africa," web site www.earthlife.org.za / campaigns / toxics / pmbr.html.

[f]J. Kupitz and V.M. Mourogov, "The Role of Small and Medium-Sized Reactors," The Uranium Institute 23rd Annual International Symposium (1998), web site http: / / uilondon.org / uilondon / sym / 1998 / kupitz.htm.

Pebble Bed Modular Reactors: A New Lease on Life for Nuclear Power? (Continued)

of 86 percent). In addition, the significant improvement in thermal efficiency that would be achieved by using the direct Brayton cycle would allow PBMRs to use less fuel and, thus, produce less spent fuel. As a result, the nuclear waste disposal problem could be reduced.[g]

Finally, Eskom has suggested that PBMRs would reduce the risk of nuclear arms proliferation, because they use only 9 percent enriched uranium as a fuel, and the spent fuel generated would have little value as a weapons component. If, as Eskom plans, South African PBMRs become widely exported, the need to export a uranium fuel capable of being transformed into a nuclear weapon would be greatly reduced.

South Africa's PBMR technology has gained the interest of energy policymakers from abroad and of some foreign private-sector investors. Researchers from the U.S. Nuclear Regulatory Commission (NRC) and the Department of Energy recently visited South Africa to meet with Eskom's design team, and U.S. Secretary of Energy Bill Richarson stated a desire to cooperate with the South Africans.[h] One U.S.-based company, PECO Energy, has joined with British Nuclear Fuels Corporation in making financial commitments to the venture. PECO's parent company, Excelon Corporation, began discussions with the NRC in late 2000 and early 2001 about building PBMRs in the United States.

Many critics, however, contend that it is doubtful that Eskom will, in the end, build a unit that will be competitive with other electricity production technologies, particularly in a deregulated environment. Eskom has been criticized for adopting overly optimistic estimates of construction costs ($1,000 per kilowatt of capacity) and total generating costs (1.6 cents per kilowatthour, including construction, operation, maintenance, fuel, insurance, and decommissioning costs),[i] which are about those for a conventional coal-fired power plant in the United States. One reason for the low estimated costs of building a PBMR is the assumption that many of the safety features required for conventional reactors, such as a containment building, would not be needed. The need for a traditional containment structure for PBMRs has not been demonstrated, because even a total loss of the gas coolant would not produce any radioactive releases; however, critics are concerned about the proposal to build and operate any nuclear reactor without containment.

Moreover, underlying Eskom's financial assumptions is a very low discount rate of 6 percent. Given that the capital costs of a nuclear plant determine in large measure whether construction is economical, a higher discount factor could easily undermine the financial viability of PBMRs even if all the other claims for the technology were realized. If, however, Eskom meets its goal of completing the construction within 2 years, the borrowing costs for the project will be less critical. Still, the PBMR is an untested technology from a commercial standpoint, and the success of the South African demonstration project will in large measure determine its viability.

[g]S. Thomas, "Arguments on the Construction of PBMR Reactors in South Africa," web site www.earthlife.org.za/campaigns/toxics/pmbr.html.

[h]R. Smith, "U.S. Backs South African Effort To Develop Nuclear Reactor—Eskom Seeks Global Investors in Power Project—Design Said To Be Meltdown Proof," *Wall Street Journal* (June 15, 2000), p. 4.

[i]Uranium Information Center, *Nuclear Issues Briefing Paper 16* (April 2000), web site www.uic.com.au/nip16.html.

North America

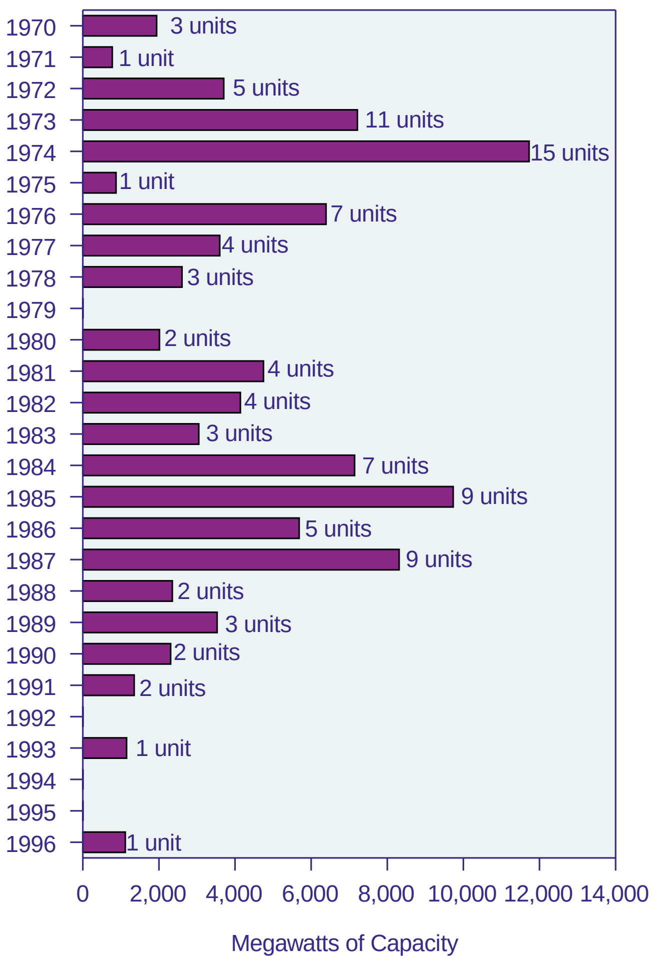
United States

The United States is expected to reduce its reliance on nuclear power significantly over the forecast period, from 20 percent of total electricity generation in 1999 to less than 12 percent in 2020. Only a few years ago it seemed likely that there would be numerous early closures of nuclear power plants in the United States; however, several companies have recently applied to the U.S. Nuclear Regulatory Commission (NRC) for extensions of reactor operating licenses. Reductions in operating costs over the past decade have made fully depreciated nuclear plants more competitive, even as electricity markets are increasingly being deregulated.

In March 2000, Baltimore Gas & Electric (BG&E) was the first U.S. utility to receive an extension on the legal operating life of a nuclear power plant. License extensions of 20 years were granted by the NRC for BG&E's Calvert Cliffs 1 and 2 reactors, expanding their potential operating lives out to 2034 and 2036. In May 2000 the NRC granted a similar 20-year extension for Duke Energy's three-unit Oconee station beyond its original 40-year operating license [***23***]. Oconee's license was scheduled to expire in 2013, but the extension moves the end of the license periods for units 1 and 2 to 2033 and for unit 3 to 2034. In February 2000, Southern Company submitted a license renewal application for its Hatch nuclear plant, and Entergy submitted a renewal application for its Arkansas Nuclear One unit. As of January 2001, according to the NRC, license renewals were being sought for roughly 40 percent of U.S. commercial nuclear power plants [***24***].

In 2000, nearly one-third of U.S. nuclear units were 30 years old or more. No nuclear power plants are currently under construction in the United States, and there have been no new reactor orders since 1978. Construction permits for the last units built (Palo Verde 1, 2, and 3) were issued in 1976 [***25***]. Most of the nuclear power plants that came on line during the building spree of the early 1970s received 40-year operating licenses and are scheduled to be retired around 2015 (Figures 66 and 67). Given that no nuclear power plants are currently in the planning or construction stage, in large measure the industry's capacity over the 2010-2020 time frame will be determined by the extent to which the industry seeks life extensions from the NRC, the degree to which the NRC grants such extensions, and the degree to which the industry decides to use the extensions that are granted.

Figure 66. Operating Licenses Issued for U.S. Nuclear Reactors, 1970-1996

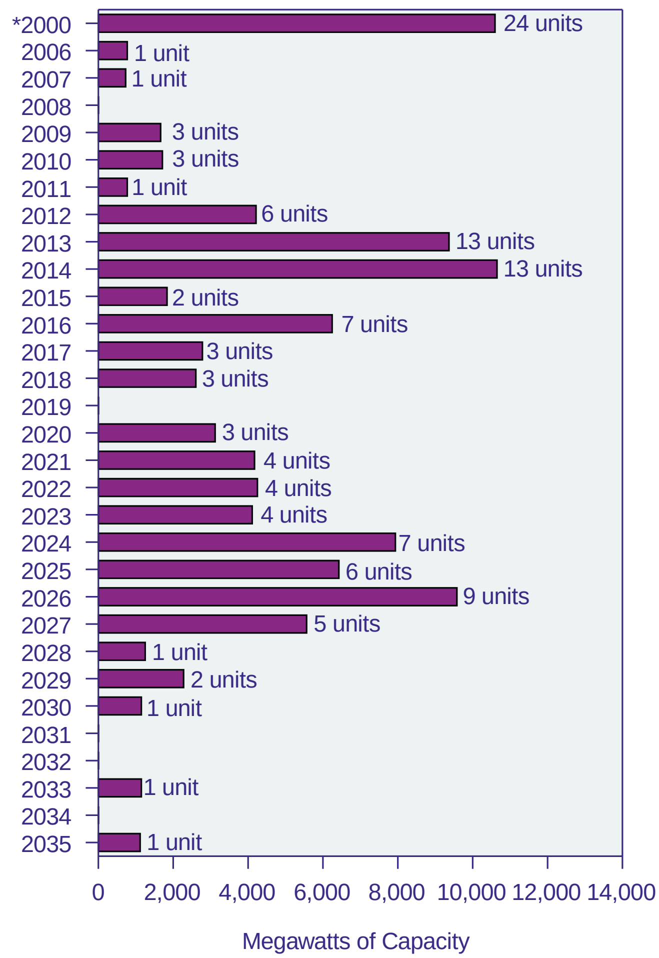


Source: U.S. Nuclear Regulatory Commission, *Information Digest 2000 Edition*, NUREG 1350, Vol. 12 (Washington, DC, June 2000), Appendix A, pp. 97-110.

Although the pursuit of a license renewal is not an insignificant undertaking (estimated at between $10 million and $20 million per reactor [***26***]), the fact that a utility may seek and receive a renewal for a nuclear power plant is not a guarantee that the life extension will be used. There is no guarantee, for example, that the economics of nuclear power relative to other sources of energy will remain stable or improve in the future. In comparison with the cost of decommissioning a nuclear unit, however, a license renewal is relatively inexpensive, and therefore some companies may choose to pursue the potential opportunity that a license renewal confers. Obtaining an extension does not require a company to undertake the capital expenditures needed to keep the unit running, which would be far greater than the cost of obtaining the license.

Since 1997, a wave of consolidation has occurred in the U.S. commercial nuclear power industry through

Figure 67. Operating License Expiration Dates for U.S. Nuclear Reactors, 1964-2035



*From 1964 through 2000

Source: U.S. Nuclear Regulatory Commission, *Information Digest 2000 Edition*, NUREG 1350, Vol. 12 (Washington, DC, June 2000), Appendix A, pp. 97-110.; and S.R. Hatcher, "Global Development of Nuclear Power," *Nuclear News*, Vol. 43, No. 3 (March 2000), p. 57.

transactions that have included company mergers and acquisitions, purchases of individual nuclear generation assets, combining the operational activities of nuclear plants owned by different companies, and sales of minority ownership shares back to majority owners. The first merger occurred in 1997, when PECO Energy Company and British Energy formed a joint partnership, AmerGen, for the express purpose of buying nuclear power plants. AmerGen has purchased five nuclear power plants to date and has plans to purchase as many as 20 plants in total. AmerGen was involved in the first purchase of a U.S. nuclear plant in its entirety in December 1999, when it bought the Clinton plant.

AmerGen and a handful of other companies are emerging as major holders of U.S. nuclear assets. Entergy, for example, has announced plans to spend $1.7 billion over 5 years to build a portfolio of 12 to 15 nuclear power units, and Duke Energy, Constellation Energy Group, and Northern States Power have also indicated interest in acquiring nuclear units [***27***, ***28***]. In addition, PECO and Entergy are involved in two of the largest mergers in the history of the U.S. nuclear power industry. Unicom and PECO completed a merger in October 2000 that created the Nation's largest nuclear utility. The combined company, Exelon, owns 17 percent of the Nation's total nuclear generation capacity, with annual revenues of $12 billion.

The largest merger on record among U.S. utilities, involving the FPL Group of Florida and Entergy Corporation of Louisiana, also involved the second largest consolidation of U.S. nuclear assets. The combined debt and equity value of the merging companies is $27 billion, and the value of the merger is estimated at $13.9 billion. The combined company will own 11 percent of U.S. nuclear generation capacity and will be the largest utility in the United States. If all the mergers currently pending are completed, the five largest owners of U.S. nuclear capacity will account for 40 percent of privately held U.S. nuclear capacity, with 100 or more owners accounting for the remaining 60 percent.

One of several factors underlying the current move toward consolidation of the U.S. nuclear industry is regulatory. The regulatory agencies that must approve electric industry mergers and acquisitions have been more inclined to do so in recent years. In addition, as deregulation proceeds, utility companies have been encouraged by State regulators either to become solely generation companies or, alternatively, to become solely distribution companies by shedding their generation assets whether nuclear or non-nuclear [***29***]. For example, the State of Massachusetts has encouraged companies to move toward vertical disintegration in order to open up the State's wholesale electricity market to competition, and favorable stranded cost recovery decisions by State public utility commissions may have encouraged similar actions in other States.

From a company perspective, operating several nuclear units may allow for greater economies of scale and more favorable procurement options. Another attraction for potential buyers of nuclear assets has been their relatively low price. In some cases, the selling price of nuclear plants has actually been negative, taking into account that the price has sometimes exceeded the value of the nuclear decommissioning fund transferred from seller to buyer. This was particularly true for some of the earliest unit sales.

By one measure, whereas thermal generation capacity in the United States has sold for two times book value, or roughly $350 per kilowatt, most of the earlier nuclear capacity sales have gone for about $80 per kilowatt [***30***]. Some of the earlier purchases of nuclear assets were made for a small fraction of book value. For instance, on November 19, 1998, Boston Edison Corporation (BEC) reached an agreement with Entergy to sell its Pilgrim nuclear plant. The selling price was $121 million. Entergy agreed to pay BEC an additional $80 million for plant and fuel, $10 million for additional fuel at closing, and $31 million for nuclear fuel credits [***31***]. The book value of the plant was $700 million [***32***]. The deal also called for BEC to turn over to Entergy a $466 million decommissioning fund.

In another early sale, AmerGen purchased the Clinton nuclear plant for $200 million, even though it cost Illinois Power $4.25 billion to build it. In the Clinton sale, AmerGen assumed full responsibility for the decommissioning. Illinois Power ceded $98 million in decommissioning funds to AmerGen and is committed to transfer additional funds sufficient to fully fund the eventual decommissioning of the Clinton reactor.

More recently, however, prices for nuclear power assets have risen markedly. For instance, in February 2000, Entergy agreed to pay the New York Power Authority $967 million for Indian Point 3 and Fitzpatrick, a record high for nuclear sales to that date [***33***]. Dominion Resources competed in the bidding process with Entergy.

In August 2000, Dominion Resources bid a record $1.3 billion for the three Millstone units owned by Northeast Utilities (including the closed Millstone unit 1), or roughly $591 per kilowatt of installed capacity [***34***]. Dominion paid $1.2 billion for the plant and related facilities along with $105 million for fuel, purchasing units 1 and 2 in their entirety and 93 percent of unit 3. In December 2000, Constellation Energy Group announced that it was purchasing Nine Mile Island unit 1 and 82 percent of Nine Mile Unit 2, a total of 1,550 megawatts of capacity, for $950 million or $613 per kilowatt [***35***]. The higher prices paid for nuclear assets in those recent sales may reflect not only the quality of the assets sold but also an improved environment for nuclear power in the United States.

Canada

Canada's nuclear electricity generation is projected to increase by 1.7 percent per year between 1999 and 2020. Nuclear power accounted for 14 percent of Canada's electricity generation in 1999, but its share is expected to drop slightly, to 13 percent, by the end of the forecast period.

In late 1997 and early 1998, Ontario Power Generation (formerly Ontario Hydro) shut down seven of its older nuclear power plants, or 17 percent (4,300 megawatts) of its operating capacity. Canada still has 14 nuclear power plants currently in operation. In July 2000, Ontario Power Generation announced its planned lease of the operation of eight of its Bruce reactors, four of which were shut down in 1998 [***36***], to British Energy. In January 2001, Canada's nuclear safety commission scheduled two hearings for licenses to resume operation of three of the closed units [***37***].

Mexico

Mexico's two reactors, which became operational in 1995, took 20 years to build. Mexico is not expected to add to its nuclear capacity over the forecast period. Laguna Verde has been under criticism for unsafe operating practices in recent years. In 2000, the World Association of Nuclear Operators criticized Laguna Verde's "security procedures, radiation monitoring techniques, engineering practices, and safety culture" [***38***].

Japan

On September 30, 1999, Japan's worst nuclear accident occurred when workers at a nuclear facility in Tokaimura set off an uncontrolled nuclear reaction that resulted in the death of three workers from radiation exposure [***39***]. Nevertheless, Japan is expected to extend the operating lives of several of its nuclear power plants, The Japanese government and electricity industry also remain committed to building new commercial power reactors in the future [***40***], despite growing public concern about the operational safety of the nation's atomic power industry.

Although it is possible that public opposition to nuclear power in Japan could intensify in the future and perhaps undo the national commitment to expand nuclear generating capacity, the *IEO2001* reference case projects an increase in the nuclear share of Japan's total electricity generation, from 33 percent in 1999 to 38 percent in 2020.

Eastern European and the Former Soviet Union

Since the early 1990s, in order to allay concerns over the operation of nuclear reactors in a number of Eastern European nations, nearly $2 billion has been provided by Group of Seven nations[16] for safety measures designed to reduce the likelihood of a nuclear accident. A major goal of the effort has been to shut down the least safe nuclear reactors operating in Eastern European nations and the former Soviet Union [***41***]. The EE/FSU region has 59 reactors operating at 18 nuclear energy sites. Twenty-five are considered by the donor countries to be operating at standards below those acceptable in the West. The Western nations have set no deadlines for the shutdown of the high-risk reactors, and only two—Chernobyl units 1 and 3—have been deactivated to date.

In 1992, the International Atomic Energy Agency began a review of safety practices at Soviet-designed RBMK-type reactors. Six of the 15 RBMK plants currently in operation are "first generation" because they were built in the early to mid-1970s [***42***]. They are considered less safe than those built later. In total the Soviets built 17 RBMK units (including the 4 units at Chernobyl), of which 13 are still active. Eleven RBMK reactors are operating in Russia and two in Lithuania.

Lithuania was promised 200 million euros (about $180 million) from the European Commission and twelve other nations in grants to help ease the financial burden of shutting down its RBMK Ignalina nuclear power plant before 2005. Similar efforts are being undertaken to close down Bulgaria's Kozloduy plants and Slovakia's Bohunice plants [***43***]. Bulgaria intends to close Kozloduy units 1 and 2 in 2002 or 2003 [***44***]. Bulgaria has agreed to close Kozloduy units 1-4 "at the earliest possible date." The European Union (EU) committed 200 million euros to help Bulgaria close Kozloduy units 1 and 2 [***45***], and in February 2001 Westinghouse announced that it will modernize Kozloduy units 5 and 6 [***46***]. Both Lithuania's and Slovakia's future entry into the EU has been jeopardized by the concerns associated with their nuclear power industries [***47***].

In December 1995, the Group of Seven and Ukraine reached an agreement to shut down all units at Chernobyl by 2000 [***48***]. The Chernobyl accident in 1986 destroyed unit 4, and unit 2 was shut down in 1991. Under the agreement, unit 1 was shut down in 1996, and Ukraine shut down the last of the four reactors, Chernobyl 3, in December 2000.

South America

Among South American nations, only Argentina and Brazil operate nuclear power plants. Brazil's 626-megawatt Angra 1 began commercial operation in 1985,

[16]United States, France, United Kingdom, Germany, Italy, Canada, and Japan.

and the 1,245-megawatt Agra 2 began operation in July 2000. Construction of Angra 2 began in 1981 [***49***]. Not only did it come close to setting a record for the longest construction time of any nuclear power plant in the world, its estimated $9 billion cost was nearly $8 billion more than anticipated price tag of $1.3 billion when the project began [***50***]. Angra 3, Brazil's one nuclear power plant under construction, is expected to be brought into service in 2006 [***51***], but the decision to complete Angra 3 unit is pending, based on the performance of Angra 2. Brazil is expected to increase its nuclear capacity over the forecast period, and in 2020, nuclear power is expected to account for roughly 5 percent of Brazil's electricity generation.

Argentina, the other South American country with nuclear power, has also experienced difficulties in developing a nuclear power industry. Since the mid-1990s, Argentina has been attempting to privatize its Atucha 1, Atucha 2, and Embalse units. The Argentine senate passed a bill authorizing the packaged privatization of the three nuclear units in April 1997 [***52***]. The original intent was to raise funds for the completion of Atucha 2 [***53***], which was completed in 1999. At present, none of the plants has been privatized, even though the Argentine government has indicated a willingness to sell the units at a small fraction of the construction costs and to allow foreign investors to bid on the plants. Currently, nuclear power is responsible for about 9 percent of electricity generated in Argentina [***54***].

In 1983, Cuba began construction of two nuclear units (Juragua 1 and 2) with a total of 834 megawatts of capacity. Work on both units stopped in 1992, shortly after the collapse of the Soviet Union [***55***], and in 1998 Cuban President Fidel Castro announced that construction of the two units would be put off indefinitely. In December 2000, Cuba finally abandoned plans to complete Juragua 1 and 2.

Developing Asia

Alone among world regions, developing Asia is expected to see rapid growth in nuclear power. Nuclear power plants are currently in operation in China, India, Pakistan, South Korea, and Taiwan, and in the *IEO2001* reference case developing Asia is expected to more than double its nuclear capacity by 2020. Consumption of energy from nuclear power plants in developing Asia is projected to increase from 1.6 quadrillion Btu in 1999 to 4.6 quadrillion Btu in 2020. Increases in nuclear generating capacity are expected for all the developing Asian nations that currently have nuclear power plants in operation. By 2020, developing Asia is projected to account for 17 percent of the world's nuclear power capacity, up from 6 percent in 1999.

China

China has ambitious plans to develop nuclear power as a source of energy for electricity generation. In 1997, the government-sponsored *China Daily* stated that China would spend $60 billion to $100 billion over the next 25 years to construct nuclear power plants [***56***]. China had three nuclear power plants in operation in 1999, and by 2020 6 percent of its electricity is projected to come from nuclear power plants, up from 2 percent in 1999.

South Korea and Taiwan

South Korea has the largest nuclear power industry among the developing Asian nations, producing 97.9 billion kilowatthours of nuclear electricity in 1999. From 1999 to 2020, generation from its nuclear power plants is expected to rise slightly in absolute terms but remain steady at about 40 percent of total electricity use. Currently, South Korea has 16 units in operation and 4 units under construction.

Taiwan is the second largest producer of nuclear electricity among the developing Asian nations, at 36.9 billion kilowatthours and 26 percent of its total electricity generation in 1999. Taiwan had three two-unit plants in operation in 1999, with a total 4,884 megawatts of capacity [***57***]. A fourth two-unit plant, Lungmen 1 and 2, is under construction, and the 1,300-megawatt units are expected to be operational in 2004 and 2005 [***58***]. In October 2000 Taiwan's Premier, Chang Chun-hsiung, announced that the project would be canceled, but Taiwan's highest court ruled in January 2001 that the government's decision was unconstitutional because the president had acted without approval from the legislature [***59***].

India and Pakistan

India launched its nuclear power research program in 1954, the first in the developing world [***60***]. India had 11 nuclear power plants in operation in 1999 and 3 under construction. Operational difficulties have hampered the performance of the operating reactors, however. In addition, the government has refused to grant entry to the International Atomic Energy Agency to conduct safety tests of India's nuclear power facilities [***61***].

As a part of its Vision 2020 plan, the Nuclear Power Corporation of India has set a goal of producing 20,000 megawatthours of electricity from nuclear power by 2020. In 1999, India relied on nuclear power for more than 2 percent of its electric power needs. The *IEO2001* reference case projects that the nuclear share of India's electricity generation will rise to almost 6 percent by 2020.

Pakistan has one operating nuclear power plant with 125 megawatts of capacity [***62***]. Another plant was activated in May 2000, and when connected to the grid it will add 300 megawatts of capacity to Pakistan's nuclear power industry.

Middle East

In July 2000 Turkey's Prime Minister announced that it would no longer proceed with its efforts to construct a nuclear power plant [***63***]. The Turkish government had previously announced plans to build 10 nuclear reactors by 2020. The first plant, at Akkuyu Bay, was to be sited on Turkey's environmentally sensitive Mediterranean coast. Turkey will instead rely on natural gas imports.

With the assistance of Germany, Iran embarked on the construction of its nuclear power plant at Beshehr in 1974. Progress on the plant was discontinued during the Iranian Revolution in 1979, and a major portion of the facility was later destroyed by Iraqi bombs during the Iran-Iraq war. In 1995, Russia emerged as sponsor and developer of the plant. Construction progress at Beshehr has proceeded slowly since, however, and it is uncertain when the plant will become operational.

Africa

Among African nations, South Africa is currently the only nation with nuclear electricity generation capacity and the only nation expected to produce electricity from nuclear power over the forecast period. South Africa has two 921-megawatt reactors, Koeberg 1 and 2, now in operation, and nuclear power accounted for 7 percent of its electricity generation in 1999. South Africa's state-owned utility, Eskom, has been experimenting with pebble bed modular reactor technology since 1993 and has proposed the construction of a 110-megawatt demonstration reactor beginning in mid-2001 [***64***]. Both PECO Energy of the United States and British Energy have acquired ownership shares in the Eskom project [***65***] (see box on page 88).

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